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ABSTRACT

This discussion of the information-processing model of learning as it relates to research in educational media traces research in conceptual organization to its beginnings in mathematical models of information-processing; addresses research hypotheses concerning structure and organization, processes and processing systems, and perceptual cues; and considers ways of describing dependent variables, manipulating independent variables, and analyzing data in information-processing research. A list of references is attached. (CHC)

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Information Processing and Visual Communication: Implications of Theory for Research

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This symposium has as its aim to explore three models of learning within which research in educational media can be conducted. Its particular focus is on research methodologies appropriate to each model. It is difficult, however, to discuss research methodologies without first examining the theories upon which they are based. For information processing, moreover, it is important to add an historical perspective as well, for the information-processing model of learning has evolved steadily over the last three decades, without the same degree of oscillation and polarization that has characterized the behavioral and the cognitive models. The characteristics of research in information processing, and the methods it uses, can be traced to mathematical-mechanical models of communication of the forties and fifties. Their evolution from descriptions of how, say, telephone systems communicate information to descriptions of human cognition has caused specifics to change. Yet the basic idea of information-processing -- that information changes the likelihood of particular behaviors or cognitive phenomena occuring -- remains unchanged.

The information-processing model of learning differs from the behavioral and the cognitive models. In the case of the behavioral model, the difference is one of substance. While the behavioral model describes learning in terms of certain stimuli causing certain responses, without too much concern for what happens in between, the information-processing model concerns itself more with the reasons why stimuli are related to responses. The same could be said about the cognitive model, which suggests that the difference between the information-processing model and the cognitive model is one of degree rather than substance. For the purpose of the following, it might be helpful to think of the information-processing model as a

subset of the cognitive model. The particular approach taken by information-processing researchers to human learning and cognition focuses on the way in which information changes the way in which concepts are organized. The cognitive model is much broader.

This paper traces research in conceptual organization to its beginnings in mathematical models of information processing. At the same time, a theoretical framework for research is built up, and the information-processing model of learning is described.

Studies illustrating information processing are discussed. Finally, research strategies for visual information processing are suggested.

The most familiar form that the mathematical model of information has taken is the one given to it by Shannon and Weaver (1949). In addition to describing information flow from source to encoder, to channel, to decoder and to receiver, they developed the notion of the bit as a unit of information measurement. A bit is defined as the amount of information needed to reduce the number of alternatives by one half. For example, in a two-level hierarchy used to classify cats, dogs, snakes and lizards as mammals or reptiles, one bit of information would enable a person to classify an animal as either a mammal or a reptile, and a further bit would enable classification in one of the two sub-categories within the broader known category. On the other hand, knowing that a particular animal is not a dog would only eliminate one of the four alternatives. (Knowing that it is not a reptile would, of course, eliminate two.)

The limitations when applying this particular aspect of information theory directly to human communication were pointed out most clearly by Miller (1963).

> "Most of the careless claims for the importance of information theory arise from overly free associations to the word

> 'information'. This term occurs in the theory in a careful and particular way. It is not synonymous with 'meaning'. Only the amount of information is measured -- the amount does not specify the content, value, truthfulness, exclusiveness, history or purpose of the information."

The bit may be a useful unit for the telecommunications engineer. But for the psychologist, its exclusively quantitative nature limits its usefulness because it cannot permit the measurement of those things in which the psychologist is primarily interested. However, at a less specific level, the idea of information reducing the number of alternative outcomes to a particular event by half, or, if you will, increasing the probability of a particular behavior occuring after a given stimulus, has a central place in learning theory. It is this thread that can be traced from the early attempts to quantify information for engineers, right up to the present.

In the early sixties, several researchers tried to adapt this basic tenet of information theory to psychology, and to relate information to meaning. Garner (1962) suggested a two-step process to achieve this. The first step was to extend information theory so that the probability of a certain outcome occuring would be predicted from the combined probabilities of many pieces of information, rather than just one. The second step, following closely from the first, was to develop the notion of information as structure.

In the first instance, Garner suggested that since the human being is extremely complex psychologically, the notion of a single bit of information reducing uncertainty by one half is just not adequate to describe learning. For Garner, uncertainty in a learner can be ascribed to many sources at once, and can act, moreover, on many aspects of the learner simultaneously. As a result, the uncertainty of a given outcome must be attributed to many things. For Garner, this leads to bivariate, and multivariate uncertainty.

For example, if a learner is to classify a square, a rectangle, an equilateral triangle, and an isoceles triangle into two categories, it can be done in many ways. In the case of univariate uncertainty, the figures would be classifiable by one feature only, for example by the number of sides. In this case, if the learner knew that a certain figure were not three sided, he would be able to reduce the number of alternatives by half, and would have acquired one bit of information. However, learning is rarely that simple. If the figures also varied in size, they could be classified as large or small, as well as three or four-sided. This is an example of bivariate uncertainty, where the number of alternatives would not necessarily be reduced by half if the same amount of information were given. Were the figures also to vary in color, weight, the material from which they were made, and so on, the certainty with which one could predict the way in which they would be classified would be greatly reduced. This, obviously, is an example of multivariate uncertainty.

Given the fact that uncertainty has many sources in human learning, Garner went on to relate information to meaning. He achieved this by distinguishing between meaning as signification, and meaning as structure. Signification is defined as "the particular specifying or indicating relation for any single event or symbol"(1962, p. 141). In a way analogous to univariate uncertainty, if a learner knows what one event is, the other related event can be predicted with certainty. There is no ambiguity. Meaning as structure is defined as "the totality of relations between events" (1962, pp. 142-143). Since meaning is in this case affected by relationships among many events, the certainty of outcomes is far less predictable. We are dealing with multivariate uncertainty. The differences between signification and structure can be illustrated by reference to learning a foreign language. We learn significations when we learn the

meanings of words, one to one. We learn structure when we learn the grammar and the idioms of the foreign language. Learning that French "chien" means English "dog" is not particularly useful unless the speaker can use the foreign word in meaningful sentences in combination with other words, and knows that calling a Frenchman a "son of a bitch" does not have the same effect as it would upon an English speaker.

Defining meaning as structure in this way makes information theory much more useful to the learning researcher. It allows the quantification of meaning in terms of the probability of a concept being associated with any of a number of other concepts. It also leads to the study of the way in which learners organize ideas. Instead of simply saying that a learner knows that "chien" means "dog", or that he does not, we can say that the learner is not sure that it means "dog", and thinks it could mean "cat" or "chair". And we can assign estimates of probability to these alternatives. The learner could be 75% sure it means "dog", 15% sure it means "cat" and 10% sure it means "chair". Put another way, we could say that the concept "chien", for the particular learner, is made up of 75% "dogness", 15% "catness" and 10% "chairness". Instructing the learner will alter these probabilities, by supplying information in such a way that the qualities of cats and chairs are suppressed, and "dogness" approaches 100% of the meaning of the concept.

Research into meaning as structure has taken many forms. However, researchers have frequently used word association in order to estimate the relationships among concepts, that is, the probability that one concept will solicit another. Deese (1962, 1965) studied the patterns formed by free word associations to sets of words that were themselves conceptually related. Subjects made free associations to words associated with "Spring".

For each possible pair of words, the number of common associations was counted and expressed as a proportion of the total number of responses. This produced a number between 0 and 1 which gave an estimate of the relatedness of each word in each pair, Deese's "relatedness coefficient". If the coefficients for all pairs are placed in a matrix, then it becomes apparent that patterns are formed by the interrelationships of words in the set. For example, in Deese's study, "insect", "bug", "fly" and "butterfly", had relatively high relatedness coefficients with each other. Other clusters also occured. In this way, the structure of the conceptual domain "Spring" became apparent through the amount of associative meaning shared by pairs of words within it.

The word-association technique has some interesting theoretical implications for research in information-processing. It suggests that the meaning of a word or picture can be defined in terms of the meaning it has in common with other words or pictures. For example, if the relatedness coefficients between cat and other animals are the following: "dog" .4, "lion" .3 and "porcupine" .1, then the meaning of "cat" can be said to have 40% in common with the meaning of "dog", 30% in common with "lion" and 10% in common with "porcupine". The remaining 20% is meaning unique to "cat". Furthermore, the overlapping of concepts that this implies means that the reduction of alternatives by giving information is by no means straightforward. For meaning to become clarified, it is necessary for a learner to be given information that allows specific discriminations to be made between concepts, not just a crude subdivision of the conceptual domain into halves.

It is the need for information that permits discrimination that leads to the next step in our consideration of information processing.

Olson (1970) defined information as "any perceptual or linguistic cue that reduces the number of alternatives to the intended referent". The notion of uncertainty reduction is still present in this definition; and two new elements have been added. The first of these is the idea of perceptual or verbal cues. The second is the idea that a communicator intends a message to refer to something specific. The first brings information theory into the media camp, for we are, by profession, purveyors of verbal and perceptual cues. The second relates information theory to learning, for it suggests that the giving of information, as perceptual and verbal cues, allows the consumer of that information to narrow down, through discrimination, what it was that the giver of the information meant. Taken together, these two notions lead to a consideration of how information is processed, for there is an implication that different verbal and perceptual cues will be effective in different ways in the reduction of alternatives to referents.

Word association has been used to study the way in which perceptual and verbal cues reduce the number of alternatives to intended referents. Shavelson (1972) instructed subjects in Newtonian mechanics over a period of several days, and administered word-association tests before, and at various points during the instruction. When the matrices of relatedness coefficients, calculated for all pairs of words naming concepts to do with mechanics, were compared to a matrix of coefficients representing the "intended" structure, derived by digraph analysis (Harary, Norman and Cartwright, 1965), it was found that instruction caused the way in which learners structured the domain to become increasingly similar to the intended structure. At the outset, the amount of meaning shared by the concepts, and the probability that one would elicit another, were minimal.

However, instruction, largely through verbal cues, reduced this uncertainty significantly. Winn (1980a, in press), conducted a similar study, where verbal and perceptual cues were provided. Instruction in food chains consisted of text plus a diagram in which the relationships among animals in a food chain were presented in terms of the distances between them. In the sequence "hawks eat snakes eat mice eat plants", hawks are "further from" mice than they are from snakes, and appeared further from them in the diagram. Again, it was found that instruction brought about an increase in the similarity between martices derived from word associations and a matrix representing the intended structure.

These two studies show that information, presented in verbal or perceptual forms, reduces learner uncertainty about what the content to be learned intends to communicate. They also suggest that the key to information processing lies in the way in which learners organize concepts. Information processing involves the perception, organization, storage and retrieval of concepts. Of these, organization is the key. Conceptual organization determines how we perceive, and how we remember. In its turn, conceptual organization is determined by perception and memory. What we know influences what we see; what we see influences what we know.

Current theory proposes that concepts are organized by one or both of two cognitive systems, the visual-spatial and the verbal-sequential, (Fleming, 1977; Kosslyn and Pomerantz; 1977; Anderson, 1978). The dual-code theory of processing and memory (Paivio, 1971, 1974) suggests that, although these two systems are interrelated, information received as verbal cues tends to activate the verbal system, and information in imaginal form is processed by the visual system. The organization of concepts in spatial images or in word-like strings is therefore determined largely by the form in

which information is perceived. Other factors, such as learner aptitudes and the use to which learners expect to put the information have been discussed elsewhere (Salomon, 1979; Winn, 1980b, in press).

The visual-spatial information processing system works by organizing concepts in meaningful visual images. For example, Simon (1972) reports that the learning of noun paired-associates is improved if the learner is instructed to create a mental image incorporating both elements of the pair. It is easier to recall "cigar" as an associate to "whale" if the learner creates an image of a whale smoking a cigar. In this case, the creation of an image increases the probability of the correct associate being given to the stimulus word during the recall trial. It contains more information. Likewise, in some circumstances, the additional information provided by the abundant perceptual cues in pictures increases the probability that pictures will be more accurately recalled than words, and explains how paired associate tasks are made easier if the concepts are represented in pictorial form (Paivio and Csapo, 1973; Paivio and Yarmey, 1966).

The verbal-sequential system organizes concepts in linear fashion. A useful metaphor here is "semantic distance". In the food-chain study (Winn, 1980a) mentioned above, a diagram made explicit the distances between concepts in the predator-prey sequence -- a linear process. It was found that the diagram helped high-verbal students organize the concepts in a way that more closely resembled the intended structure than text alone. The fact that this difference was not found for low-verbal students supports the claim that learners with a more efficient verbal-sequential system gain more information from perceptual cues about sequences of concepts than do learners in whom this system is less

efficient. In another study (Winn, 1980c, in press), it was found that a diagrammatic treatment helped high-verbal learners classify insects into superordinate categories (depending on the type of metamorphosis they undergo) more successfully than low verbal learners, providing further evidence for the relationship between verbal-sequential processing and concept organization. The probability of correct classification was increased for learners with an effective sequential processing system by providing cues about the semantic distance between concepts.

If information processing is considered to be the way in which concepts are perceived, organized, stored and retrieved, with organization largely determining the other three, then information processing must be studied within the context of the visual-spatial and verbal-sequential systems. The studies mentioned above, and countless others, have shown that relationships exist between the form in which information is presented (verbal or imaginal), the way in which concepts are organized, and the probability that the meaning that a learner derives from a communication will be the same as the intended meaning. The rest of this paper addresses the implications of this for the design of information-processing research studies. The discussion will be limited to research in visual information processing.

Research Hypotheses

The first question that needs to be addressed is: what is it that research in visual information processing should study? From the previous discussion, three areas emerge for research. These are: structure and organization, processes and processing systems, and perceptual cues.

Hypotheses tested in information-processing research deal with the interrelationships among these three areas.

Information-processing researchers are particularly interested in the structure and organization of conceptual domains. Studies were described above in which the interrelationships among whole sets of concepts were described in terms of probabilities or relatedness coefficients. Information-processing research addresses questions about the changes in such conceptual organization as a result of information being given, rather than recall of information, trials to criterion, and so on. Researchers are interested in finding the most efficient ways of providing information that will change these structures so that intended learning takes place. They are interested in finding out the relationships between inter- and intra-subject meaning -- that is, the degree to which patterns of concepts are common among members of groups of subjects, or are unique to individuals.

Research in information processing seeks to discover more about the systems by which concepts are organized. This involves the study of perceptual, sensory and cognitive systems in the widest possible sense, ranging from the study of perceptual mechanisms, such as vision and hearing, to study of the spatial and sequential processing systems, even to neurological processing. Most familiar is research that seeks to discover more about how the verbal-sequential and the visual-spatial processing systems work. Typical of this research are studies in mental imagery. The research question here is: to what extent is visual information processed in picture-like images? Studies by Kosslyn (1973, 1975) on noticing details in pictures, and by Shepard (1978) on the rotation of letters, all suggest

that visual information is processed in images, which can be scanned and manipulated in memory, just as real pictures can be. Fleming (1977), Anderson (1978) and Winn (1980b, in press) have addressed this issue in detail. Research has also shown that when learners are required to process visual information for purposes that do not require the scanning of images, such as in problem-solving of certain types, then information is processed as word-like propositions. Information-processing research seeks out relationships between the demands of the learning task and the system that processes the information. It also deals with learner aptitude and processing systems. This is because aptitude tests are often the best way of discovering the degree to which a particular processing system is developed in a learner.

Finally, information-processing research studies the role of various visual and verbal cues in helping learners to organize concepts (reduce uncertainty), and in activating the visual and verbal processing systems. Although visual cues tend to be processed by the visual system, and to give more information about visual concepts, with verbal cues serving the same purpose for the corresponding system and concepts, it is not always that straightforward. For instance, the question of translating information from verbal to visual and vice-versa is an important one for researchers to address, particularly since educators frequently defy the logic of expecting students to perform and be tested in the same medium as the one in which they were given information. (The possible role of propositional processing as a cognitive inter-lingua, serving to translate from imaginal to verbal forms has been discussed elsewhere. See Kosslyn and Pomerantz, 1977.)

Research hypotheses for information-processing studies will therefore make reference to relationships between organization and processes,

organization and visual cues, and processes and visual cues. Examples might be: predicting that high-verbal subjects would structure a particular conceptual domain more effectively than low-verbal learners (structure-process); that concepts learned from pictures will be better organized than concepts learned from text (structure-cue); and that high-verbal learners would structure concepts learned from a diagram more correctly than those learned from a picture, the reverse being true for low-verbals (process-cue).

Dependent variables

Such phrases as "structure more effectively" and "better organized" require careful operational definition. Ways of empirically describing concept organization from word associations were described above. Other methods also exist, such as the construction of tree diagrams by learners (Waern, 1972). Whatever the method, the dependent variable will appear as a pattern of numbers which indicate the interrelationships among concepts. However, such patterns are insufficient in themselves for hypothesis testing. Research almost always requires the comparison of scores across treatments or across trials. The question arises: how does one compare matrices of relatedness coefficients across groups? Before statistical tests, such as analysis of variance or multiple regression, can be performed, concept patterns have to be expressed in simpler form. A way of doing this is to compare each subject's matrix to a standard, "correct", matrix, in order to determine how similar they are. Research hypotheses about structure then become statements of the similarity of subjects' matrices to the standard, as a function of various treatments,

predictors and so on. Differences between patterns of concepts and the "standard" pattern can be estimated by calculating euclidean distances between the matrices derived from learners' free associations and the standard matrix (Shavelson, 1972; League, 1977). This reduces each subject's matrix to a single score, which is a measure of the similarity of organization between the two matrices. This presupposes, of course, that the standard can be expressed in matrix form. However, if semantic distances between single concepts can be estimated, then a matrix of these can be created. One such method for doing this is digraph analysis (Harary, Norman and Cartwright, 1966).

Another, simpler, way of measuring organization is to give posttests requiring subjects to classify concepts they have learned into categories. If the classification scheme consists of several dimensions, and multiple categories, then concepts will indeed be closer to some and further from others. The pattern of concepts a subject has learned will emerge from the way in which they are classified. Dependent variables will therefore have to do with the accuracy of classification, based on as many or as few categories as the researcher wishes. Research hypotheses will be concerned with predicting correct classification scores as a function of various visual cues, learner aptitudes and so on.

Independent variables and predictors

The question now is: what is information-processing research interested in manipulating, and how? The answer is easiest to find for hypotheses that have to do with the effects of visual cues on concept organization. Obviously, visual cues have to be manipulated. However,

it is important for this kind of research that such manipulation be more finely tuned than the typical picture-versus-word, or color-versus-black-and-white-picture study. Research in information processing must be concerned with the properties of various pictorial cues. For example, spatial arrangement within a visual is an important visual cue. However, little knowledge would be gained about information processing by comparing two treatments with and without spatial arrangement. It would be more useful, for example, to compare two different types of spatial arrangement, one of which stressed sequence of concepts, the other concept patterns. Should the former arrangement prove to be the most effective, than something could be concluded about how the information was processed. If the researcher also knew something about the structure of the content that was communicated to the learners, then conclusions about the appropriateness of sequential arrangement in visuals could be drawn.

If, in addition to their scores on the experimental task, the researcher was unable to distinguish between learners on the basis of their preferred, or most efficient, processing system (spatial or sequential), then even more information about spatial arrangement in visuals would be forthcoming. This suggests that ATI studies, in which spatial and verbal ability are used as predictors, are appropriate for the study of visual information processing. The various aptitude tests that are commonly available are probably the best way researchers have of determining which processing systems are likely to be activated in different learners. Of course, the predictions that can be made on the basis of aptitude scores will often be overriden if the content to be learned is better processed by another system, or if the learner has certain expectations about the use to which the information is to be put.

Information-processing studies have also manipulated instructions given to subjects with considerable success. The best examples of this are studies in paired-associate learning, where subjects have been instructed to form, and even to draw, associative images, to embed paired-associates into sentences, to use various other mnemonics, or simply to memorize (see, for example, Paivio and Foth, 1970). Instructions such as these cause information to be processed in certain ways, controlled by the experimenter. In a similar way, instructions could also encourage subjects to process concepts sequentially or spatially, and could even override the natural tendency of subjects to process certain types of information in specific ways. Instructions to subjects is a variable that has received insufficient attention by researchers in information processing.

Data analysis

Data from information-processing research can be analyzed in the usual ways. However, a word needs to be said about the analysis of concept structures. Information about relationships between concepts is complex and detailed. A way of distilling it, by calculating euclidean distances between matrices, was suggested above. However, other methods exist for making concept interrelationships, described in matrices, more amenable to interpretation. These are factor analysis and multidimensional scaling. Both of these techniques reduce complex systems of variables to a limited number of factors or dimensions, which represent the underlying structure. Deese (1965) used factor analysis to help him interpret the associative meaning of the concepts to do with "Spring". In this case, factor analysis identified clusters of concepts that seemed to belong together. Winn (1976)

used simultaneous factor analysis in order to compare the underlying structure of associations made to words and to pictures. Shavelson (1972) used multidimensional scaling in order to help him interpret his data on cognitive structures formed for Newtonian mechanics. In each case, analysis simplified complex data, and revealed underlying structure.

A word should also be said about predictors in ATI studies. Since scores on many of the sub-tests in aptitude batteries are often correlated, it is not possible to interpret a significant interaction in terms of, say, the spatial or the verbal system. If verbal and spatial scores are correlated, then high-verbals will also tend to be high-spatial. It is therefore often necessary to partial out variance caused by aptitude scores in which the researcher is not interested, in order to "purify" the aptitude under investigation. It should be emphasized that this should be done when an aptitude score is to be interpreted as indicating something about an information-processing system. If an aptitude is defined operationally as the score a learner makes on a certain test, then partialling out variance in this way is not necessary.

The discussion of implications of information-processing theory for research studies has been limited to just a few of the hypotheses, variables and analysis procedures that are in fact of interest. This is inevitable, because human information processing is a vast and complex topic. However, the elements of research design that were mentioned have produced useful information about how people produce information, within the confines of conceptual organization. They are also likely to have application beyond this area. Undoubtedly, researchers will develop and adapt other techniques to their needs. It may even be more hindrance than help to try to distinguish between information processing and other types of research. They are all

related, as this symposium will no doubt demonstrate. Hopefully, however, these few pointers will help other researchers unravel the complexities of how people process information.

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